A CASE STUDY OF EFFECTS
OF ACIDIC AIR POLLUTANTS
ON CROP YIELDS

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DISCLAIMER

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I. PURPOSE AND BACKGROUND

A. PURPOSE

In its report to Congress about the dangers of air pollution, the National Academy of Sciences (NAS (1975) estimated that acid rain caused about 1/2 billion dollars of damage each year, or about 30 dollars per ton of sulfur emitted. Since the NAS study has been published, increasing damage to ecosystems in the Adirondeck Mountains and Scandinavia have been attributed to acid rain. With our increasing dependence on burning coal and the subsequent probable decrease or at best maintenance of air quality, there remains lingering doubts about whether acid rain will lead to unbearable damage of our ecosystem. One of the most important components of that ecosystem is American agriculture. Will continued levels of air pollution jeopardize our 90 billion dollar farm industry?

In order to comprehend the agricultural risk of current levels of air pollution, we need to know how dangerous pollution is to farm yields. Most of the current knowledge about crop dose-response curves comes from experiments. There are two basic types of experiments available to researchers: 1) controlled and 2) natural. Obviously, the extent to which one controls the environment is a continuous variable so that, in practice, all experiments are a combination of each type. However, for expositional purposes, it is helpful to distinguish between each approach for each has its strengths and shortcomings.

The controlled experimental approach runs deep in the natural sciences. The concept is to control all differences among groups of observations except the treatment variable one is trying to comprehend. All of the differences in behavior across the groups is then attributed ***to*** the treatment variable. The more carefully unwanted variation is kept random across the groups, the more unbiased the resulting dose-response curve.

Natural experiments seek to learn information from variations in nature which are unplanned. Like the planned experiments, one tries to identify groups which receive different treatment levels. Because other disturbances may frequently coincide with the treatment variable, it is also necessary to take statistical precautions to separate desirable from undesirable effects. One of these precautions is to choose a sample where variation of the treatment variable is great and unwanted variations are small and random. The second precaution is to analyze the data with multivariate statistical techniques which permit some of the variation across groups to be attributed to variables other than the treatment variable.

The more carefully uncontrolled variation is accounted for, the more accurate the results. The more unwanted variation is kept random across treatment groups, the more unbiased the resulting dose-response curves. Thus, the goals of unplanned and planned experiments are similar, they just use different techniques.

The strengths and weaknesses of planned versus unplanned experiments vary with the situation. If unwanted variables coincide with the treatment variables in nature, unplanned experiments will generally have difficulty determining precise unbiased dose-response curves. If the natural environments are complex with multiple causes and effects, the natural experiments may be unbiased but they will not be accurate.

The natural experiments are not without difficulties. However, the planned experiments are not always superior. If the natural environment is complex, the planned experiment may give accurate dose-response curves in one situation but these results may not be generalizeable. If the response to treatments in the relevant range are small, size of the experimental groups may need to be large. Carefully planned experiments are often prohibitively expensive with large populations.

The planned experiments are consequently performed in either poorly controlled settings or at extraordinary treatment levels. With poorly controlled settings, one rapidly approaches a natural experiment. With extraordinarily high treatment levels, it is possible to identify dose-response functions but they relate to treatment levels of no practical importance. Thus, in general, the unplanned experiments give uncertain results of relevant effects whereas the planned experiments give more certain results of less relevant effects.

The fraction of the acid rain literature concerned with agricultural crops is predominantly planned experiments. Whereas the results of these studies combats our ignorance about acid rain, the absence of natural experimentation with acid rain is unfortunate. Planned experiments simply cannot simulate the variety of environments crops are grown under. Thus, the results of the planned studies may not be generalizeable to vast croplands. The levels of acid rain in most parts of the country are modest implying the agricultural responses will be subtle. Again, planned experiments are rarely performed with population sizes large enough to detect small effects. Finally, planned experiments unfortunately frequently fail to measure the most relevant response of agricultural crops to pollution, how does acid rain effect the value of yield per acre?

Instead, scientists look for more sensitive measures of effect such as photosynthesis rates or sulfur absorption rates. Although these sensitive responses permit smaller samples (making the experiments cheaper) and provide helpful clues to the causal mechanism of final effects, these biological responses give virtually no indication of the economic magnitude of the damage acid rain may cause. Planned experiments are helpful in the pursuit of understanding acid rain. However, planned experimentation is not clearly the most helpful method of determining the best immediate policies towards acid rain. There is clearly a need to study the effect of acid rain on major agricultural crops using a natural experimental method.

The central purpose of this study is to examine the effects of air pollution and acid rain on two major United States crops: corn and soybeans. We are specifically attempting to estimate the economic damage to an acre of either of these two crops due to exposure from sulfur dioxide and acid rain.

The approach used in this study is a natural experimental method. A site has been chosen where groups are exposed to varying but realistic treatment levels of both pollutant measures. The site was chosen carefully to minimize the confounding influences of other factors commonly spatially associated with air pollution. A multivariate statistical analysis is performed using the available data at the site to isolate the effects of acid rain on cropland yield variations.

A secondary benefit of this exploratory analysis of natural experiments is an identification of available data sources, methodlogical problems, and recommendations for future research. In the course of the study, various sources of data were examined, some of which proved fruitful and others of which could not be used. How the data should be collected, which data seems most important, and what statistical techniques are appropriate is also discussed. Finally, recommendations are made for areas where the natural experimental approach is promising.

The studies which are reviewed in the following section are generally planned research where either laboratory ***or*** field exposures of plants are carried out. The more recent of these studies generally utilize realistic doses in accordance with natural conditions.

B. REVIEW OF RELEVANT LITERATURE

Acidic pollution has been found to be a widespread phenomenon which is present throughout the United States. A network of stations set up by EPA to monitor acid rain indicates that many areas stretching from California to New England experience rainfall with a pH below 5.0. There are also probably high levels of dry deposition of acid pollutants in many areas, although this has been less well measured. In the area around Sioux City, Iowa, where this case study was conducted, background levels are known to be roughly pH 5.0 for rainfall, indicating that under natural conditions, the area is on the border of significant acidity but is not yet highly acid. Individual sources such as power plants, however, may affect the acidity on a more localized basis, especially given the background acidity. This provides a motive for analysis of the composition, air and soil transport pathways and effects of acidic pollution known from previous research.

1. Composition

Although power plant plumes and other air pollution sources contain numerous chemical compounds (Hulett et. al. 1980, Evens et. al. 1980) the bulk of acidic pollution of interest to scientists is derived from chemical species related to oxides of sulfur and nitrogen. Specifically, sulfur dioxide and nitrogen dioxide have received the most study (Witten et. al. 1981, Chang et. al. 1980) probably due to the availability of widespread monitoring data and ease of measurements. In recent years, however, it has become clear that oxidized forms of these pollutants, sulfates and nitrates (HSO_4^-, HNO_3^-, etc.) may cause more damage than the unoxidized forms, or may at least work through differing mechanisms.

Thus composition and distribution of sulfates and nitrates is now being studied by EPA and others (Altshuller 1973, 1980, Brezonik et. al. 1980, Homolya and Lambert 1981, Witz and Uendt 1981).

The term "acid rain" has come into widespread use as an indicator of acidic pollutants present in the atmosphere which may be transported over long distances. The term grew out of pioneering studies overseas (Swedish Royal Ministry of Foreign Affairs 1972) and in this country (Likens and Borman 1974) which focused on wet deposition and consequent effects on aquatic and forest ecosystems. The term "acid rain" is, however, somewhat a misnomer, or at least misleading since it focuses only on wet deposition (Kerr 1981). In fact, both wet and dry deposition may be of importance in assessing air pollution effects (Mendelsohn 1979), especially in plants where the uptake mechanisms of air pollutants may take more than one form (Shea 1977). Acidity of rainfall as measured by pH is therefore only an indicator of the fact that the falling precipitation has swept through an atmosphere containing ionized sulfur and nitrogen oxides which contribute hydrogen ions and therefore acidity prior to deposition.

The relative ratios of sulfur and nitrogen compounds in acid precipitation has not been well studied except in a few specific geographical areas. Research at EPA's Corvallis (Oregon) Environmental Research Laboratory have found that a 2:1 mixture of sulfuric and nitric acid (to form sulfates and nitrates) gives a fairly accurate representation of most ambient acid rain in the United States (Lee and Neely 1981).

2. Meteorology and Transport Mechanisms

Studies of acid rain throughout the world have shown that long range transport mechanisms exist which are effective at distances of several hundred kilometers or more (Fisher 1975, Brezonik *et. al.* 1980, Pack 1980). Such transport causes increased acidity across large geographic areas. Since these large areas differ drastically in climate, they do not provide a useable basis for prediction of effects based on variation within a natural environment, the approach used by this study. Within a distance of 100-150 kilometers (or within 100 miles), however, pollutant desposition from a single source are governed by local meteorology. For single sources, dispersion models are widely used to determine atmospheric transport of pollutants (Witten 1981). Although many complex dispersion models exist (Ellis *et. al.* 1980), these are most applicable to areas with complex terrain, in shoreline areas, or areas of high atmospheric instability. In regions of consistent winds and smooth terrain, the Gaussian Plume Model provides a simple but efficient analyical method (Green *et. al.* 1980). Such a model has been used for the present case study.

The physics and chemistry of power plants plumes have been explored at several power plants in the eastern United States, usually through use of aircraft or remote sensing (Ulthe *et. al.* 1980, Davis et. al. 1979). It has been found that the vertical location and internal structure of plumes vary depending on weather conditions (relative humidity, etc.) and time of day (Ulthe *et. al.* 1980). Chemically, it has been found that sulfur-sulfate conversion occurs within the plume although some researchers concluded that conversion occurs quickly within a few kilometers of the plant (Forrest and Newman 1977), while others have found slower, continuing conversion mechanisms (Davis *et. al.* 1979). Sulfur dioxide-sulfate conversion (and similarly nitrogen dioxide-nitrate conversion) is known to be dependent on relative humidity and other factors, however, relationships are not totally clear for these parameters (Hershaft *et. al.* 1976).

Sulfur and nitrogen oxides may reach the ground through either wet or dry deposition (Mendelsohn 1979). Dry deposition processes tend to favor deposition of SO_2, while wet deposition is more conducive to sulfate formation (Altshuller 1980, McNaughton and Scott 1980). Much of the dry deposition of SO_2 tends to occur within a few kilometers of the source (Mendelsohn 1979), while wet deposition varies widely depending on timing and frequency of precipitation events. The parallel mechanisms for nitrogen dioxide and nitrate deposition are not well known but are probably similar since they involve oxidation reactions which are basically parallel to those of sulfur. Some study has been conducted on acute effects of NO_2 on plants (Bennett et. al. 1975).

3. Pathways to Plants

The two principal atmospheric deposition processes act differentially in the way they affect plants. Dry deposition of sulfur dioxide is well known to directly affect plant leaves, causing lesions, spots or other damage (Jacobson and Hill 1970). Sulfur dioxide which is deposition on soil may adhere to soil particles or later undergo interactions to soluble forms. On the other hand, sulfate which falls on leaves is generally washed off by subsequent precipitation, with the greater portion ultimately reaching the soil. Portions which remain can, however, still damage leaf structures (Evans, et. al. 1977). The sulfate radical, particularly in its acidic forms, is highly soluable and can be easily absorbed into plants through root uptake of sulfate ions (Kumar and Singh 1979).

On leaves, sulfur and nitrogen oxides are absorbed through openings into the leaf tissue (stomata) and can be assimilated into plant metabolism or the photosynthetic process through the action of enzymes (Gerwich et. al. 1980). The mechanisms by which this occurs may vary between different species. Corn, in particular, having a four-carbon chain basis for photosynthesis and sugar reduction (C_4 metabolism) carries out sulfur and nitrogen assimilation in two different parts of the leaf tissue (Gerwin et. al. 1980), whereas soybeans and other three-carbon (C_3 metabolism) plants assimilate both elements in the same area.

In the soil, uptake of sulfur and nitrogen is selectively regulated in most plants. However, changes in soil concentrations of these elements may influence the selective ability of the plant (Labeda and Alexander 1978) as well as changing the chemical processes occurring in the soil which are necessary to plant growth and development (Labeda and Alexander 1978, Keuss 1975). In the air or soil, relative humidity or soil mositure has been shown to affect the action of sulfur and nitrogen pollutants in their uptake by plants (Al-Ithaui et. al. 1979, McGlaughlin and Taylor 1980, Heck et. al. 1975).

4. Effects on Plants

Sulfur and nitrogen oxides have well known and recognized effects on plant tissues. Most early studies, however, focused on visible foliar injury. Such foliar injury is very important in leaf crops such as lettuce and tobacco (Thompson 1975), however, it has been found that crop yield effects are often the best measure of damage (Davis 1972). Yield studies have been performed for such crops as wheat (Newmann 1979), cotton (Brewer and Ferry 1974), oat seedlings (Marchesani and Leone 1980), truck crops (Thompson 1975, Heck et. al. 1965), corn (Thompson 1975, Newmann 1979), and soybeans (Davis 1972, Tingey et. al. 1971, Hofstra 1977, Heagle et. al. 1974).

These crop yield studies define relationships between total air pollution doses and yields or dose-effect functions (Hershaft et. al. 1976).

Studies on a wide spectrum of agricultural crops have recently been carried out as part of an ongoing cooperative program between the U.S. Environmental Protection Agency's Corvallis Environmental Research Laboratory (CERL) and the Oregon State University Agricultural Experiment Station. These experiments have tested over 40 crops in greenhouse and field conditions under exposures to acid rain. The crops used include corn and soybeans, (Lee et. al. 1981, Cohen et. al. 1981).

From the above discussion it is apparent that there is a considerable amount of literature pertaining to acidic pollution effects on vegetation. In the following discussion, we will, however, focus only on corn and soybean studies which are relavant to this report.

Effects of air pollutants or any chemical species on plants may vary widely due to differential plant response or environmental conditions. Corn and soybeans, for instance, are considerably different in their needs for nitrogen and sulfur. However, the results of studies on both crops show that under some conditions, impacts of air pollution may be damped.

Soybeans are capable (due to symbiosis with a micro-organism contained in the roots) to fix nitrogen into forms utilizable by plants. Therefore, soybeans do not require nitrogen from the surrounding environment. Soybeans, however, produce oils and proteins, which require, among other elements, significant amounts of sulfur. Sulfur in utilizable forms is, therefore, beneficial to soybeans (Kumar and Singh 1979). This need for low levels of sulfur explain the results of several studies which show little damage or actual enhancement of soybean yields at low levels of SO_2 (Lee 1981, Heagle et. al. 1974, Muller et. al. 1979).

Corn apparently requires little or no extra sulfur but it does require nitrogen from the soil, preferably in the form of soluble nitrates. Thus there may be a balance phenomenon depending on the sulfate-nitrate ratio in acid rain and the total acidity and buffering capacity of the soil (Reuss 1975). It has been shown in recent studies that corn is affected detrimentally by SO_2 (Laurence 1979, Cohen et. al. 1981, Lee et. al. 1981, Thompson 1975, Newmann 1979). Yield effects have ranged from a few percent to nearly 10 percent (Lee and Neely 1980, Lee et. al. 1981, Newmann 1979). The mechanisms for this damage could be inhibition of soil nitrification (Labeda and Alexander 1978), or direct effects on the plant itself (Newmann 1979).

II. METHODOLOGY

The methodology developed during this project is aimed at producing techniques for measuring past relationships between air quality and crop yield in existing data. The techniques developed are applicable both for cross-section and time series analysis where sufficient data exists.

A. DEFINITIONS AND CRITERIA

Initially, project methodology was set up to proceed through a series of data gathering and analysis steps, testing various methods for effectiveness and efficiency. The five major steps were:

- site selection
- physical data collection
- crop data collection
- data analysis (by year)
- time series analysis

The purpose of our site selection criteria was to produce a site having substantial predictable variation in pollutant exposure with as little confounding variation as possible. The resulting criteria was to find a large remote polluter in a heavily agricultural area. We therefore sought a sizeable source of acidic sulfur and nitrogen compounds. For the purposes of this study, acidic pollutants are defined to be sulfur or nitrogen in the forms of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and sulfate ($SO_4^{=}$, HSO_4^{-}) molecules or radicals which may be present in acid rain or suspended in the atmosphere. The sources focused on were power plants and smelters which emit these compounds.

Physical data collection involved contact with appropriate agencies to determine wind speed, direction, rainfall, and other relevant meteorlogical parameters. Crop data collection was carried out through nationally available compilations and through individual, on-site interviews. Crop data was collected for only major crops, along with information pertaining to planting, fertilizing, harvest, and other factors.

Data analysis was carried out for the most recent crop year (1980) and for those years in which national compilations of crop yield exist. Comparisons were then made between various years and correlated against air quality changes to produce time series data.

The metholological steps which are summarized above and explained in more detail below are directed toward producing dose-effect functions on relationships between air quality and crop yield. The analysis is predicated on the assumption that environmental fluctuations can be, to a large extent, factored out and that the relationships which remain show causative changes. These relationships are for chronic low-level air pollutant levels which actually occur in the environment. By focusing on crop yield, we have chosen to concentrate on bio-economic indicators of effect as opposed to pure biological (i.e. photosynthesis change) or economic (i.e. crop marketability) effects.

B. SITE SELECTION PROCESS AND RESULT

The purpose of the site selection phase of this study was to select several candidate areas and then one specific site on which to conduct a case study investigation. At that site, attempts were to be made to establish chronic dose-effect relationships between air quality and crop yield.

Studies of chronic effects are typically difficult due to large natural variability of environmental conditions such as other emissions sources. We, therefore, attempted to select areas which were relatively uniform in terms of climate and other natural factors and in which the source selected for dose-effect analysis was somewhat dominant. This latter condition tended to preclude urban areas.

The selection process involved two screening steps, the first directed at identifying several candidate areas for investigation. The second step was designed to select a particular study site within the best candidate area.

Criteria for selection of the candidate areas focused primarily on crop distribution with secondary emphasis on air quality factors. Since the purpose of our study is to define yield effects which have economic implications, we first identified major economic crops in the U.S. as summarized in Table II-1. We then conducted a literature search (see Section I-B) to identify crops known to be susceptible to acidic pollutants. As discussed above, studies showed that for the major economic crops, corn, soybeans, cotton and certain fruits and vegetables were known to be susceptible (Davis 1972, Brewer and Ferry 1974, Jacobsen and Hill 1970, Thompson 1975 unpubl.). Tobacco is known to be susceptible to ozone but not necessarily to sulfur pollution (Heck <u>et. al.</u> 1966). Studies have not been carried out for wheat or hay, however, oat seedlings (Marchesani and Leone 1980) and ryegrass (Bleasdale 1973) have proved susceptible to sulfur dioxide damage.

Four criteria were developed which maximize the probability of deriving meaningful dose-effect relationships as shown in Table II-2. Based on the above known crop sensitivities and the criteria shown in Table II-2, five candidate areas were defined (Table II-3). In two of the areas the major crop (wheat) is one which is not known to be susceptible to acidic pollutants.

TABLE II-1. Major Economic Crops
(Source: U.S. Census of Agriculture 1974)

Crop	Value (millions of dollars)	Major States	Acreage (millions)
Corn	15,000	Illinois	9.9
		Iowa	12.7
Wheat	7,000	Kansas	11.0
		North Dakota	10.0
		Montana	4.7
Soybeans	7,600	Illinois	8.3
		Iowa	6.9
		Missouri	4.1
Hay	5,000	Wisconsin	4.1
		South Dakota	4.3
		Minnisota	2.8
Cotton	2,300	Texas	4.5
		California	1.1
Vegetables & Melons	2,800	California	0.74
Orchards	2,800	California	1.7
		Florida	0.9
Tobacco	1,800	North Carolina	0.37
		Kentucky	0.18
		South Carolina	0.07

TABLE II-2. Section Criteria for Candidate Case Study Areas

1. High crop density and value (major crop states)
2. Existence of crops of known or probable susceptibility to acidic air pollutants
3. Relatively low background pollution levels
4. Absence of large, nearby urban centers

TABLE II-3. Selected Candidate Case Study Areas

State(s)	Locale	Crop(s)
Iowa	N/A	Corn, Soybeans
Texas	N/A	Cotton
Montana	Eastern	Wheat
Washington	Eastern	Wheat
California	Sacramento Valley	Truck Crops, Fruit Trees

While use of a wheat area might make an interesting case study, its use on a trial case study was not felt to be justified. Because corn and soybeans are the most important crops grown in the United States (see Table II-1) and are known to be susceptible to air pollution, we chose those crops to study first. Both Iowa and Illinois are areas where these crops occur in major quantities. Illinois was not selected due to the large number of urban centers, (including St. Louis, Mo. located west of the southern part of the state) leaving Iowa as the prime candidate state for investigation.

Once Iowa was established as a prime candidate for the first case study, more detailed data on air quality, meteorology and land use was collected on regions within the state. Table II-4 lists the criteria which were developed for selection of a specific site within the candidate area. For Iowa, we gathered pollutant emission data on the major Air Quality Control Regions (Table II-5) and selected areas which had major sources outside large urban complexes (i.e. Quad-cities, Omaha-Council Bluffs, etc.).

The three potential site areas selected were AQCR's 065, 086 and 091. Ultimately, 065 and 091 were deemed unacceptable because they were downwind of the Ames and Des Moines urban centers. The Sioux City AQCR (086) was therefore selected.

Once the AQCR was identified, source emission data was procured from the Iowa Department of Environmental Quality. This data revealed that the largest source in the area was the Iowa Public Service Power Plant, Port Neal Facility, in Sioux City. This point source contributes almost all of the sulfur pollution in the AQCR. The plant began operation in the late 1960's which unfortunately precludes a before-after comparison of pristine and polluted environments. The emissions, however, have dramatically increased over time due to the addition of new boilers and increased electrical power production for the region. The

TABLE II-4. Study Site Selection Criteria

1. Located in rural area
2. Relatively low background of SO_2 and NO_2
3. Existing large source of sulfur and nitrogen pollutants (i.e. power plant)
4. Evaluation of statewide ambient air quality data
5. Existence of sufficient long-term ambient monitoring stations
6. Availability of adequate meteorological data (usually requiring presence of an airport)
7. Emissions source old enough to provide several years of chronic level emissions, but which is either new enough for before/after analysis, or with emissions levels which show dramatic changes over time.
8. Screen major pollutant sources in rural area against first seven criteria

TABLE II-5. Iowa Air Quality Control Regions and Associated Sulfur Dioxide Emissions

(Source: National Emissions Inventory 1973)

AQCR	Location	Sulfur Dioxide Emissions (tons/yr.)
065*	Burlington-Keokuk (S.E.)	22,000
068	Dubuque (E. Cent.)	8,000
069	Quad Cities (E. Cent.)	66,000
085	Omaha-Council Bluffs (W. Cent.)	6,200
086*	Sioux City (N.W.)	15,700
087	Sioux Falls (S.W.)	0
088	Northeast Iowa	48,000
089	North Central	2,500
090	Northwest	400
091*	Southeast	13,000
093	Southwest	800

*Sites selected after initial screening

source was, therefore, found to be adequate for time-series analysis.

The Sioux City Port Neal Power Plant was selected as the point emission source for the case study. The plant is located 12 miles south-southeast of Sioux City as shown in Figure II-1. The plant is a typical fossil fuel fired power plant, burning mainly coal.

C. PHYSICAL DATA COLLECTION

Physical data collected included the categories of meteorological air quality and emissions data. As subsequent data on crop variability was compiled, it became apparent that soil types were also an important physical factor. These data were collected on a county basis where available.

1. Soils

Information on local soils was collected from Soil Conservation Service surveys of each county available. However, these were available in less than half of the counties under study.

In general, data from the soil surveys was found to be only peripherally useful. It was not possible to use soil type as a quantitative measure of variability for the regression analysis. Soil surveys are mapped in such great detail that it was difficult to obtain an overview of conditions. However, in some cases, general types of soil found in a particular county helped explain certain patterns of crop yield in a qualitative manner (see Section III-A).

For sites east of the Mississippi River, Dr. William McFee of Purdue University has inventoried soil types and related

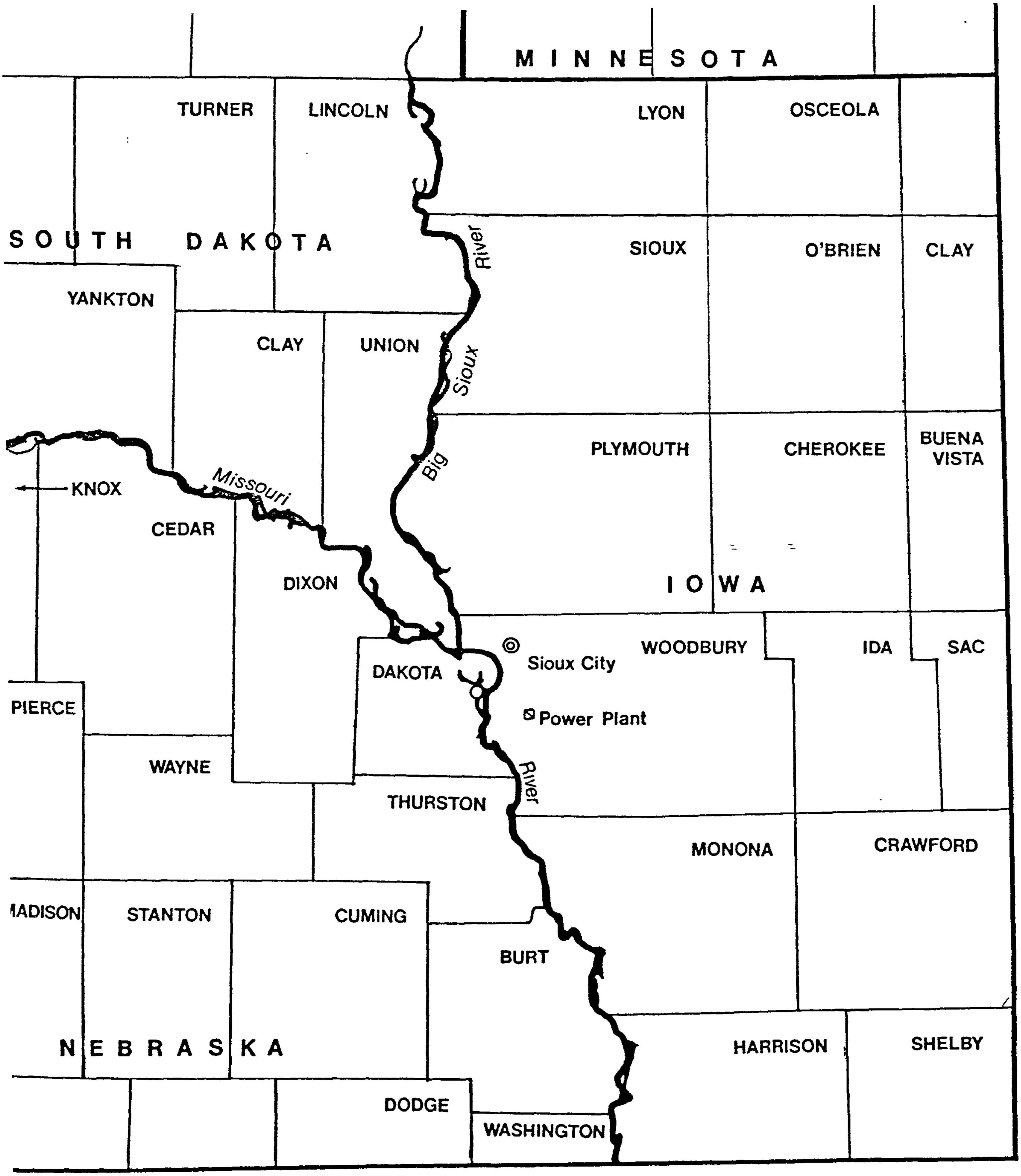

Figure II-1. Power plant and vicinity.

specific soil characteristics to buffering capacity against acidic deposition (McFee 1980). He has classified the soils into broad categories on a statewide basis for most eastern states. These categories could be used as the basis of a regression variable indicating soil sensitivity to acidic air pollution (dry deposition) and acid rain. Unfortunately, the state of Iowa has not yet been included in Dr. McFee's data base.

2. Meteorology

Meteorological data for the Sioux City area was obtained from the National Weather Service in Sioux City. The records indicate long term averages of wind and precipitation conditions on a month-by-month basis.

Data was collected on average windspeed, maximum windspeed, wind direction, monthly precipitation, cloud cover and ceiling height. These data were extracted on a month-by-month basis, and were used as input to the meteorological model. In the cases of wind direction and speeds, monthly data were used to derive seasonal averages. This was justifiable on the basis of data consistancy over each season. The meteorological model itself is discussed further in Section II-E.

3. Air Quality

Air quality monitoring data for the area within 100 miles of the power plant is collected by both federal and state agencies. The U.S. Environmental Protection Agency maintains the National Ambient Air Quality Sampling Network. The site vicinity falls into EPA Region VII (Iowa, Nebraska), Region II (Minnesota) and Region VIII (South Dakota). We collected ambient sulfur dioxide data for all stations within the 100 mile radius.

Nitrogen dioxide and sulfate data were found to be non-existent or to use measurement methods not approved as reference methods by EPA and so were not used for analysis.

In addition to the Federal Network, each state maintains air quality stations. These are generally in different locations than federal monitors, but have similar geographic distribution. Air quality data were supplied by the Iowa Department of Environmental Quality, the Nebraska Department of Environmental Control, and the State Department of Health in South Dakota. The federal network was deemed sufficient in Minnesota since only a few counties at the fringe of the study area were involved, and since those counties do not lie in any direct wind path to or from the site.

3. Plant History and Emissions

The Iowa Public Power, Port Neal Facility Plant, has been on line since 1964. It began operations with one coal-fired boiler. Subsequent boilers were added in 1972 (No. 2), 1975 (No. 3) and 1979 (No. 4). With the additions of boilers, have come changes in overall production and emissions of sulfur dioxide and other pollutants.

Data from the Port Neal Power Plant was supplied both by the Iowa Department of Environmental Quality and by the plant management. Emissions data was obtained for the years 1969, 1972, 1973, 1974, 1978 and 1980.

In some cases, it was necessary to derive total sulfur dioxide emissions from data on sulfur content of fuel. In such cases, we followed the procedure of the Iowa Department of Environmental Quality by assuming that sulfur in the fuel was burned and oxidized completely. Emissions were then calculated on a gm/sec basis (average emission rate) by using information on fuel used and number of operating hours.

D. CROP DATA COLLECTION

Data on crops was collected for corn and soybeans, the two major economic crops in the Sioux City area which are known to be potentially affected by air pollution. Total crop yield per acre of each species was used as the dependent data parameter. In addition, information on natural variables and crop management techniques was collected to be used as independent variables in the multi-variate regression analyses.

Initially, two forms of crop data collection were employed. Part of the purpose of this project was to test the efficiency of data collection and reliability and usefulness of each form of data. The two types were: 1) uncompiled data on individual farms and 2) compiled data aggregated on a county basis. Each type is discussed below along with advantages and disadvantages.

1. Individual Farm Data

Procedure: Early in the project, important variables associated with crop yield variation were identified. Prior to commencing on-site data collection, these factors were formulated into a questionnaire. The questionnaire was to be used as a standard basis for interviews of individual farms. The questions were directed toward measurements that farms would remember or have easily available in records. The focus of the questions was on factor inputs and production techniques which might vary accross farms and introduce undesired variations in yield across farms.

The questionnaire form used is shown as Table II-6. Farmers were asked to supply information only for the previous growing season, since contacts with local county extension agents indi-

Table II-6. Crop Production Questionnaire

Farm Location: ____________ County ____________ State ________

Address: ______________________________

Map Coordinates: ______________________________

Farm Size (acres) __________

Major Crops: ____________, ____________, ____________,

Is corn grown? ________ For grain? ________ Other? ________

Are soybeans grown? ________ For Beans? ________ Other? ________

What was corn (for grain or all purposes) yield for 1980?

Total ____________ Acres ________ Yield/acre ____________

Variety planted? ______________________________

What was soybean yield for 1980?

Total ____________ Acres ________ Yield/acre ____________

Variety planted? ______________________________

Corn:

Was fertilizer used? ________ Acres ________ lbs/acre (wet) lbs/acre (dry)

Mixture ________________ Extra sulfur ____________

Were herbicides used? ________ Acres ________ lbs/acre ________

Total spent? ______________________________

Were insecticides used? ________ Acres ________ lbs/acre ________

Total spent? ______________________________

Was lime used? ____________ Acres ________ lbs/acre ________

Soybeans:

Was fertilizer used? ________ Acres ________ lbs/acre (wet) lbs/acre (dry)

Mixture ________________ Extra sulfur ____________

Were herbicides used? ________ Acres ________ lbs/acre ________

Total spent? ______________________________

Were insecticides used? ________ Acres ________ lbs/acre ________

Total spent? ______________________________

Was lime used? ____________ Acres ________ lbs/acre ________

Was irrigation used? Corn ______ Acres ________

Soybeans ______ Acres ____

Table II-6. (continued)

Were any crop rotation techniques used?

Corn ____________________

Soybeans ____________________

Total man/days required to plant, plow or maintain crops?

Corn ____________________

Soybeans ____________________

Total man/days required to harvest crop?

Corn ____________________

Soybeans ____________________

Were any special planting or harvesting techniques used?

Corn ____________________

Soybeans ____________________

Machinery used specifically for:

Corn ____________ Replacement Value ________

Soybeans ____________ Replacement Value ________

Both crops ____________ Replacement Value ________

Do you think your crops are being affected by air pollution?

____

Data was in: ______written, ______ verbal form.

Date: ____________________

cated that most farmers were unlikely to keep more than sporadic records for past years. The questionnaire was not administered on a widespread basis through mail distribution because such efforts usually have a low percentage success ratio (Canning and Shea 1979).

The questionnaire was used on counties which were picked along transects east, north and northwest of the Sioux City Power Plant Site. The transects were chosen in order to obtain samples which were homogeneous except for their exposure to pollutants from the power plant. The counties used were Calhoun, Ida, Plymouth and Woodbury in Iowa; Bon Homme, Minnehaha, Union and Yankton in South Dakota; and Dakota County, Nebraska.

Candidate farms were identified within each county through checking records of the County Extension Service. Once names, addresses and telephone numbers were obtained, a phone call was usually made to determine the farmers acquiescence to an interview. The interviewer then proceeded to several farms within the county at which response was favorable and carried out the interview based on guidance from the questionnaire. In some cases, it was necessary to modify certain questions in order to insure applicability to local conditions.

The length of the interview time was generally thirty minutes to an hour, however, with driving time and advance phone calls, a maximum of 4-5 farms in one county per day could be visited. For this reason, only 4-5 farms per county were used during the initial data collection period which was considered a trial run. The purpose of the trial run was to determine the feasibility of collecting a statistically valid number of sampling points and the relative value of individual farm data.

Survey Techniques and Data Problems: For the individual farm interviews, questions were developed which were intended to solicit easily remembered information which could be used as indicators of yield or related confounding variables. These variables represent differences in plant growth environment such as fertilizer, insecticides, or other factors. During actual collection of the data, we found that certain parameters are either too broad or too variable to be useful. Others were found to be very minor or to be not accurately reported.

Dry fertilizer and lime were found to be useful variables which tested as being significant in some cases. Wet fertilizer, however, was found to be minor in most cases or to be lumped with dry fertilizer and not reported separately. Herbicides and insecticides were only partially useful variables due to inaccurate reporting. We initially explored potential effect of crop variety upon yield, however, there proved to be too many varieties to make this a successful approach. There are several hundred varieties of corn and farmers do not keep careful records of how much of each variety is planted in their fields.

Questions pertaining to labor and farm capital were attempted but these proved unsuccessful. Farm labor was found to be very casually reported and no records are kept of the amount of effort which goes into planting or maintaining each field. On most farms even the number of laborers during the previous year was uncertain. Questions on valuation of farm machinery suffered many of the same problems. There were many types of machinery. Indices of capital such as the value of the machinery was difficult to obtain. Even value of these differed in reporting, some using purchase price, others present worth, and still others replacement values. Cost of such items as fertilizer was also found to be non-quantifiable in any uniform manner. It is, of course, possible or even probable that machinery, labor techniques and related variables are quite similar, at least for farms in a local area.

The entire survey technique of individual farms was found to have certain intrinsic problems. Memories were somewhat vague, even on the previous year's events. Given the voluntary nature of the survey, it was difficult to get farmers to take the time to refer to their records. Further, most farmers did not believe air pollution was a problem for them and so they questioned the purpose of the survey. Not only were many of the farm input questions unsuccessful, even the measurement of yield per acre is suspect. The average yield in the survey is about one half of the reported yields for the same county from state records.

Farmers did not respond well to an interviewer from outside the local area. A local person, knowing both local concerns and farming techniques would probably be a more efficient interviewer. Even with a local person, however, the problems of time inefficiency and general vagueness of the data would remain.

2. Aggregated County-Wide Data

Procedure: The second data collection method was use of the U.S. Census of Agriculture which is published on a state-by-state basis and contains county specific aggregated data from all farms which respond to a questionnaire. The Census of Agriculture is carried out every 4-5 years. We used the Census of Agriculture for 1969, 1974, and 1978 (only portions published) in order to correlate base year crop yields with varying amounts of emissions from the Port Neal facility in a time series analysis.

Crop yield data was derived from county by county listings of soybean yield and corn (for grain) yield in bushels/acre for all farms with incomes over $2500. The size restriction was made in order to help standardize and eliminate some of the effects which might result from differing crop management techniques available to large or small farms.

Dependent and independent variables taken from the Census of Agriculture data were similar to those in the questionnaire (see previous subsection). Those parameters used from the Census are shown in Table II-7.

The Census provides data which is highly standardized during any given year, however, several drawbacks to use of the data were noted. First, data are not always reported in a uniform manner for all crops. This creates difficulties in designing variables which could be useful for comparing differential effects among different species. Secondly, each succeeding census changes questions asked and data reported. This is particularly true for the 1978 Census in which we could not obtain several variables which were valuable in explaining some aspects of crop yield variation.

Survey Techniques and Data Problems: Census of Agriculture data was gathered for farms producing at least 2500 dollars worth of farm output. Farms which produce less than this amount are not clearly commercial ventures and may use ineffi-cent production methods. These small farms were eliminated in order to make the sample more homogeneous. Further, small farms only produce about two percent of each state's annual crop. The format of recorded information contained in the 1978 Census of Agriculture varied from the 1969 and 1974 pub-lished data in four categories of interest. These included commercial fertilizer, lime, insecticides, and herbicides used on crops.

Table II-7. Parameters From Field Data and U.S. Census of Agriculture

Crop	Parameter	Units	Comments
Corn & Soybeans	yield for each farm	total bushels total acres bushels/acre	
	fertilizer for each farm	total acres lbs/acre (wet) lbs/acre (dry)	have name brand
	herbicides for each farm	total acres lbs/acre (gas or dry) pts./acre (wet)	have name brand
	insecticides for each farm	total acres lbs/acre	have name brand
	lime for each farm	total acres lbs/acre	
	plant, plow, maintain and harvest crop for each farm	man/days	
Corn for grain Soybeans for beans	yield for county*	total bushels total acres bushels/acre	
Corn for all purposes Soybeans for beans		total dry tons used total wet tons used	for 1969 and 1974 only 1974 also had tons/acre
On all crops (except hwy.)	insecticide*	total acres used on	1978 data includes hwy.
For weeds or grass	herbicide*	total acres used on	1978 data also included brush on crops or pasture
For all crops	lime*	tons/acre	1978 data does not give tons/acre but total farms using and total acres used on

*farms with sales of 2500 and over

The 1969 and 1974 Census of Agriculture recorded each category as follows: commercial fertilizer applied (total dry tons and total wet tons for corn and soybeans individually), lime (total tons applied to total acres of farmland), insecticides used (total acres of crops except hay-receiving insecticides), and herbicides (total acres of crops receiving herbicides for weeds or grass). The 1978 Census of Agriculture varied the recording of data for each of the categories as described in the following: commercial fertilizer (number of farms and the total acres receiving application of fertilizer for corn and soybeans individually), lime (total farms using lime and total acres of farmland receiving lime), insecticides (total acres of crops, including hay-receiving insecticides), herbicides (total acres of crops receiving herbicides for weeds, grass or brush on crops and pasture).

Due to these changes, it was not possible to separate wet and dry fertilizer for 1978, nor are 1975 values for insecticides or herbicides strictly compatible with values from previous years. For lime, all information on actual quantity has been deleted from the 1978 data. Due to these variations, time comparisons between the data sets must be undertaken with care, and many of the effects of confounding variables must be neglected. Further, many counties did not report corn or soybean yields in 1978 for fear of disclosing private information. Combined with the fact that only Iowa has compiled the 1978 data at this time, the 1978 sample is woefully incomplete.

E. ATMOSPHERE DISPERSION MODEL

In order to compute the effect of acid rain and sulfur dioxide on various acres of cropland, it is necessary to get measures of ambient concentrations at each location. In principle, one could simply establish a matrix of pollution sampling stations across the area of study. The advantage of the sampling station approach is accuracy. With ambient measures, one no longer needs either emission data or atmospheric dispersion models which are both subject to large measurement error. The disadvantage of sampling stations is their cost (a single station may cost as much as this entire study).

An adequate netowrk of sampling stations would cost between 10 and 25 times the cost of this entire study. Although there is no question that sampling stations provide more accurate information, there is reasonable doubt whether the additional accuracy is worth the resource cost.

In any case, the approach followed in this study is to use emission data combined with an atmospheric dispersion model. The emission data, as discussed in Section C, was collected for a single power plant. Because this power plant is the sole producer of sulfur dioxide within a forty mile radius, it alone was used to predict ambient concentrations. Predicted downwind levels are within the range of monitored values, however, it is difficult to correlate actual effects of the plant due to the relatively small size of the source and the sparsity of downwind monitors.

In other case studies where there are multiple sources of pollution, it would be necessary to plot dispersion patterns from each.

A modified Gaussian plume model was used to predict atmospheric dispersion. The advantages of this model are its simplicity, the availability of the required meteorological data, and the known estimates of parameters of the model. The disadvantages of the model include its limited range of accuracy (within 100 kilometers), its inability to predict daily fluctuations in concentrations, and its inability to adjust to local terrain. In this particular application to the area surrounding Sioux City, the limitations of the model are not serious. Accurate measures of concentrations beyond 100 kilometers were not as important as the fact that these concentrations are relatively low. Daily fluctuations in concentrations are not considered nearly as important as the average seasonal concentration. The local terrain is particularly flat: a form compatible with the model. In this particular acid rain study, the Gaussian plume model should perform almost as well as any other dispersion model available (and at a fraction of the cost).

The dispersion model used in this study was first developed by Pasquill (1961), Turner (1961), Gifford (1976) and Briggs (1974). It was modifield to include dry and wet deposition as well as some elementary chemical transformations (see Mendelsohn (1979).

The plume emanating from the stack is assumed to travel in one of sixteen possible directions. Given the height of emissions, the plume disperses both horizontally and vertically according to the following equation:

$$X\ (x,\theta\ ) = \frac{2Qp\ (\theta,s)\ F_t\ (x)}{2\pi\ \sigma_z\ (s)\ u\ \ (2\pi x/(16)}\ e^{-Y_z[H/\sigma_z(s)]^2}$$

where X is the concentration at a point, x distance, and o direction, Q is the rate of emissions, $p(\theta,s)$ is the probability of weather blowing in the θ direction of type s, F_t is the transformation and deposition function, σ_z (s) is the vertical dispersion coefficient, u is the wind speed, and H is the effective height of emissions.

The transformation and deposition function F_t, is composed of three parts: wet deposition, f_w, dry deposition, f_d, and chemical change, f_c. The formula for F_t is:

$$F_t(X) = \exp(-\Sigma f_d - \Sigma f_c - \Sigma f_w + \Sigma f_w f_d + \Sigma f_d f_c + \Sigma f_w f_c - \Sigma f_w f_d f_c)$$

The wet deposition, f_w, of a pollutant depends upon the precipitation rate, collection efficiency, and drop size. Assuming an average drop size of 2mm and taking the average annual rainfall, wet deposition rates W_i should be about .005. The fraction of material removed by wet deposition by a certain distance is:

$$f_w(X) = .005 * x/N * .80$$

For more details, see Mendelsohn (1979). Wet deposition rates are assumed to be proportional to acid rain.

Dry deposition and chemical change from sulfur dioxide to sulfate are also modelled. Dry deposition is assumed to be relatively small since the land is in agricultural use [see Gudicksen (1975)]. Chemical transformation is assumed to occur at the rate of 5 percent per hour. Thus, dry deposition and chemical change are included in the dispersion modelling although in a crude manner [see Mendelsohn (1979)].

F. MULTIPLE REGRESSION ANALYSIS

In a natural experiment, many factors vary across treatment groups in addition to the desired treatment variable. In order to discover the independent effect of the treatment variable (air pollution) it is necessary to remove the influences of the undesired variations (such as in fertilizer, pesticides, irrigation, etc.). To the extent that one can model the effects of these other variables, it is possible to cleanse the response variable of their influence. One tool which is useful for this purpose is multiple regression analysis. The dependent variable in this analysis is crop yield per acre. The independent variables include the desired treatment variable (ambient pollution levels) as well as undesired effects such as fertilizer, farm size, etc. If the functional form of the regression is correct and all the undesired influences are included, one can get a perfect measure of the effect of air pollution on crop yield.

In practice, it is difficult to ascertain the exact functional form of the regression equation. Thus, one may enter a variable in a linear form but it may have nonlinear effects on crop yields. To the extent that the functional form is incorrect, one does not actually control for the undesired variation. This will result at best in loss of accuracy and at worst in both uncertainty and bias. As a first approximation, a linear regression form was used in this analysis. Other forms were then compared to the linear in order to test for strong nonlinearities.

A second difficulty in practice is including all the true independent variables. Unfortunately, there are countless factors which affect the crop yield on any given acre. There is the variable of interest, pollution, the genetic makeup of the crop, the soil, the micro weather pattern and the fertilizer, pesticides, and herbicides applied to that particular acre. It is extremely expensive to obtain accurate measures of each of these variables. Some of these factors, such as the micro weather and genetics, were not included in the regression. Other variables are included (soil, fertilizer, etc.) but may be poorly measured. The effect of these partial or full omissions is surely to lower the accuracy of the remaining coefficients. Hopefully, none of these omitted variables are consistently correlated with the treatment variable pollution. Thus, the estimated dose/response curves will be uncertain but hopefully will not be biased.

In the following study, we perform analyses both across space and across time. The source of pollution in this sample increased dramatically in the mid seventies. By comparing the effects before the increase with those after, it will be possible to obtain a crude measure of the dose/response curve. A second measure of the dose/response curve is obtained by comparing farms which have high pollution (close to the source) with others which have low levels of pollution (far from the source). In principle, either comparison should yield the same result. However, with omitted variables and incorrect specifications, it is possible that the measured responses are different. This combination of cross-section and time series analysis thus provides a robust check on the multiple regression procedures since it is unlikely that the time series errors would mimic the cross-sectional mistakes. Of course, if the regression coefficients do vary between techniques, this does not invalidate the results, it merely indicates how uncertain the results really are.

III. ANALYSIS AND RESULTS

A. CONDITIONS AT CASE STUDY SITE

The discussion below covers conditions of the environment within a 100-mile radius of the Iowa Public Power Sioux City-Port Neal Power Plant. The area encompasses 85 counties (Figure III-1) located in Iowa, Nebraska, South Dakota and Minnesota.

1. Meteorology

The area around Sioux City, Iowa, experiences a temperate climate with well defined seasons. Winter mean temperatures are typically below freezing during January and February, often with 5-15 inches of snowfall per month. Mean annual rainfall is roughly 26 inches, with most of the rain falling during the growing season. The months of April through September average more than two inches per month, peaking in June at 4.07 inches. Relative humidity varies between 62 and 82 percent depending on the season and the hour of the day. Percentage of cloudy days is less than 15 percent throughout the year.

Winds are highly seasonal. Mean monthly windspeeds vary only between 9.0 and 13.3 miles per hour with the higher windspeeds during spring months and low speeds in late summer and early fall. However, winds often gust to much higher speeds and directions change dramatically depending on the time of year.

Fastest windspeeds on a monthly basis range from 28 mph in August and September (1979 data) to 52 mph in May. During past years, storm winds during May have been clocked at 80 mph in Sioux City.

Prevailing wind direction is generally from the northwest during the fall and the winter months. During April prevailing winds

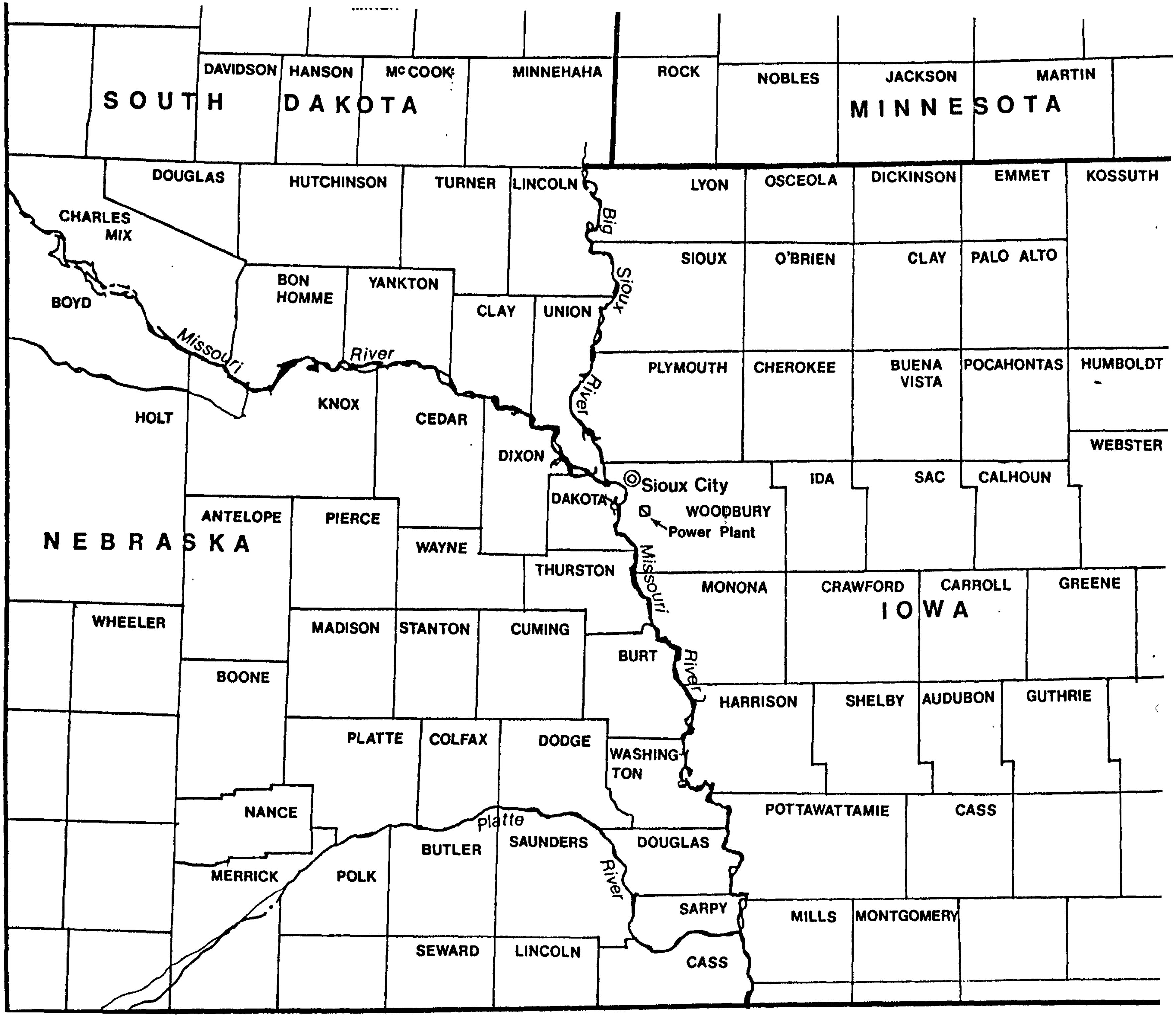

Figure III-1. Counties within a one hundred mile radius of the Port Neal Power Plant.

shift to the north-northwest, however, the direction reverses during May and the remainder of the summer, becoming south-southeast or occasionally south until the end of September. This is due to stable high pressure systems east of Sioux City during the summer months. The general windflow during the growing season is from the south-southeast.

2. Ambient Air Quality and Emissions

Ambient air quality in the Sioux City area is generally good to excellent. Background levels of SO_2 pollution are less than 10 ug/m^3 as compared to the national standard (annual mean) of 80 ug/m . This applies to Sioux City and the surrounding rural areas. Background levels are shown in Figure III-2. Levels of nitrogen dioxide are also low, typically less than 30 ug/m^3 as compared to the 100 ug/m^3 standard. Levels of pollution are somewhat higher in parts of the Omaha, Nebraska-Council Bluff, Iowa area which is located nearly 100 miles south of Sioux City in Douglas and Pottawattamie Counties. Here, some monitors have recorded 15 ug/m^3 SO_2 which is higher than Sioux City, but still well below the national standard. Winds during the growing season probably carry this pollution northward toward Sioux City, however, most SO_2 deposition can be expected to occur before reaching the Sioux City area.

The U.S. Environmental Protection Agency has prepared preliminary maps of acid rainfall levels throughout the United States. During 1979, the Sioux City area coincided with the line for pH 5.0 or slightly more acidic than the normal 5.6 for rainfall. Areas to the east are more acidic and areas to the west more neutral.

The Iowa Public Power Port Neal Plant is the largest single SO_2 emission source in or near Sioux City. It is located roughly 12 miles southeast of the city center. Emissions have varied over the years, but have generally risen with time. The plant origin-

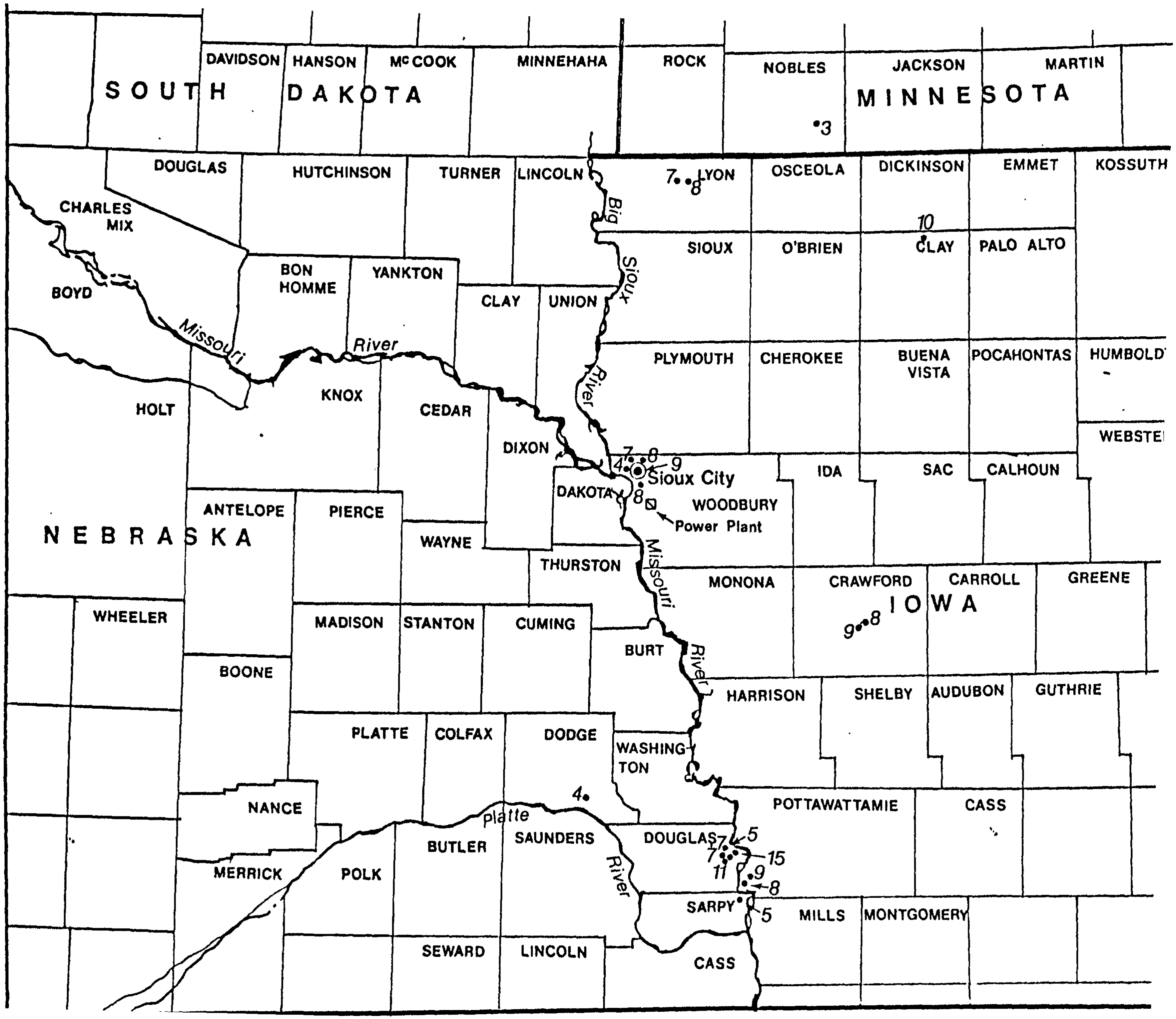

Figure III-2. Annual average SO_2 concentrations at the state and EPA monitoring stations (1978).

ally went on line in 1964 with one boiler (Hardie, letter of July 22, 1981). Boiler No. 2 was added in 1972 (Hardie, letter of July 22, 1981). Boilers No. 3 and No. 4 were added in 1975 and 1979 respectively (Hardie, letter of July 22, 1981). The increase in boilers has been accompanied by a general increase in production at the plant, although fluctuations occur in some years, typically ranging between 0.5 and 3.0 percent. Average sulfur emissions for the power plant are shown in Figure III-3 for certain years from 1969 to 1980. The SO_2 emissions calculated indicate average emissions/second over a complete year and are not adjusted for plant operating hours.

3. Land and Agricultural Conditions

Topographically the area surrounding Sioux City, Iowa, lies on a broad plateau of low rolling hills, dissected by the Missouri and Big Sioux River Valleys. Elevation ranges generally between 1000 and 1800 feet above mean sea level, with gradually rising elevations to the west in Nebraska, and lower elevations in the river valleys. Elevational differences are small enough that complex terrain dispersion models are not necessary or appropriate.

Soils in the 100-mile radius around Sioux City are highly variable in soil series, type and texture (SCS 1964, 1976a, 1976b). Most soils, however, are high in nutrients, with bottom land soils in the river valleys being particularly rich due to organic silts. In general, soils are slightly low in sulfur (Tabatabai, 1976 and personal communication 1981). Variations in soil and soil nutrients are important contributors to agricultural productivity, however, there is a lack of uniform soil classification in the area. Due to this lack, it was not possible to use soil type as a regression variable.

Crop productivity varies by county and by year. Yearly variation is probably governed by precipitation and other meteorological factors. Crop yield for corn and soybeans are shown in Figures III-4 and III-5, while those for 1974 appear in Figures III-6

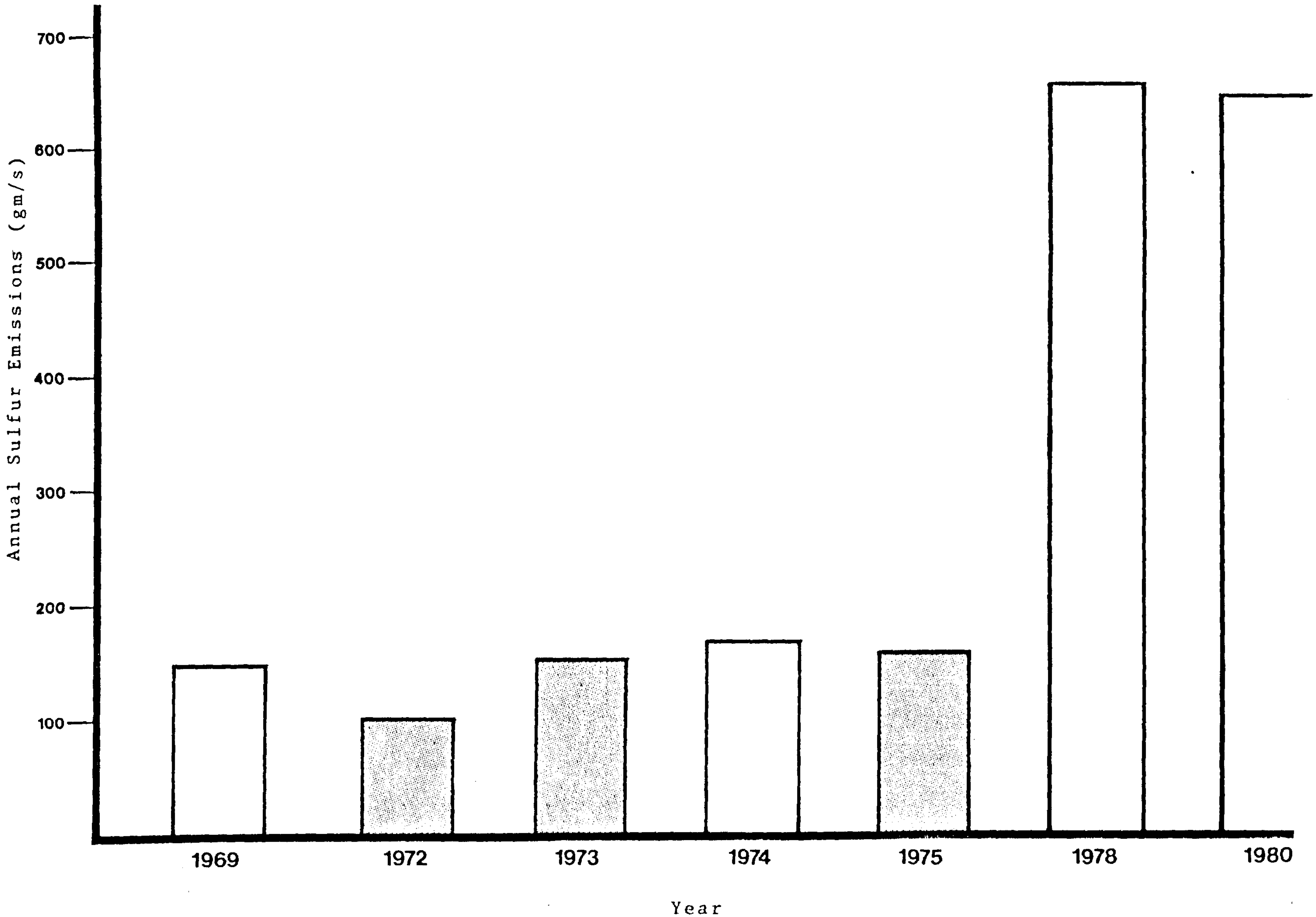

Table III-3. Sulfur emissions from the Port Neal Power Plant.

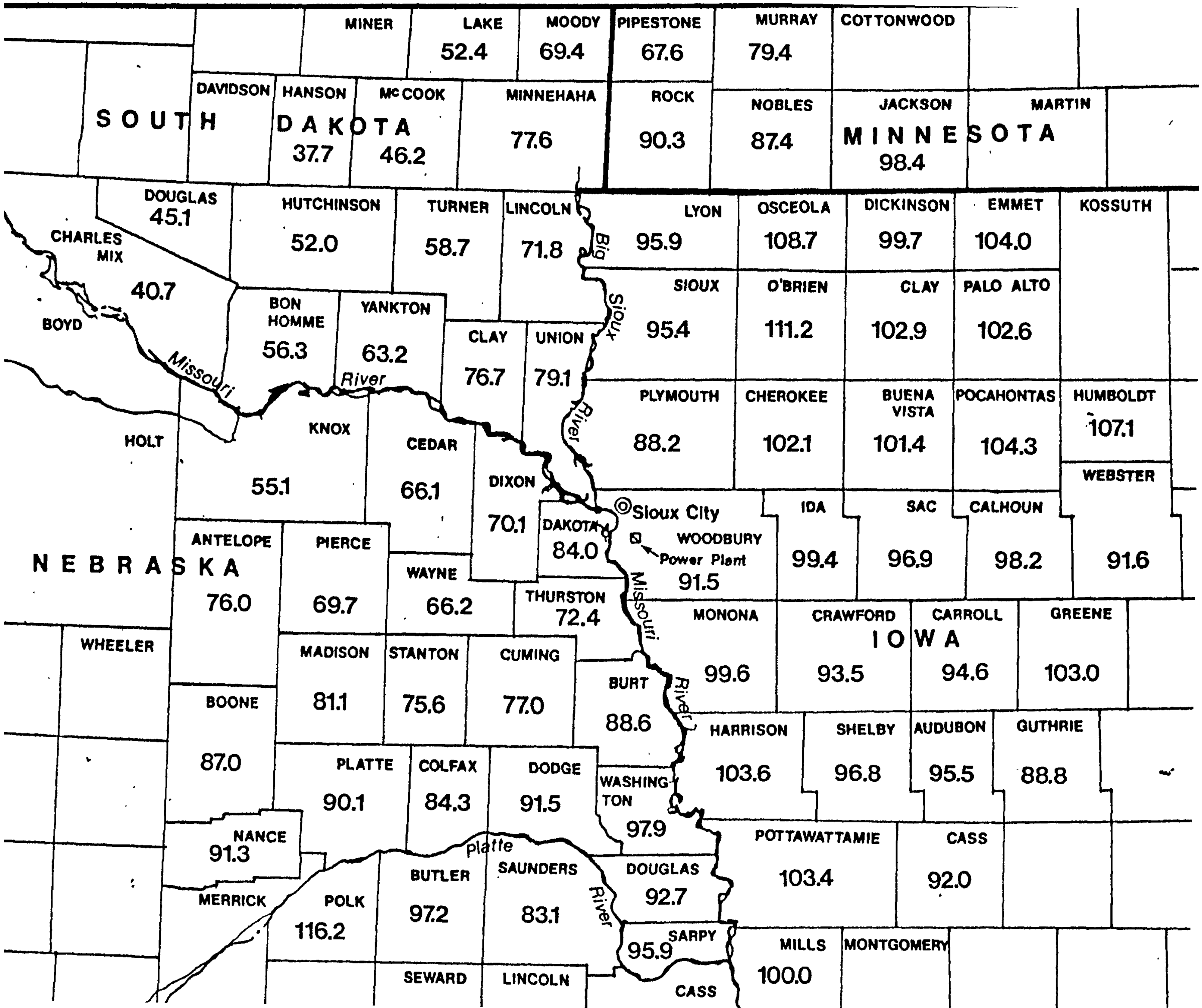

Figure III-4. Corn yields (Bushels/acre) by county; 1969.

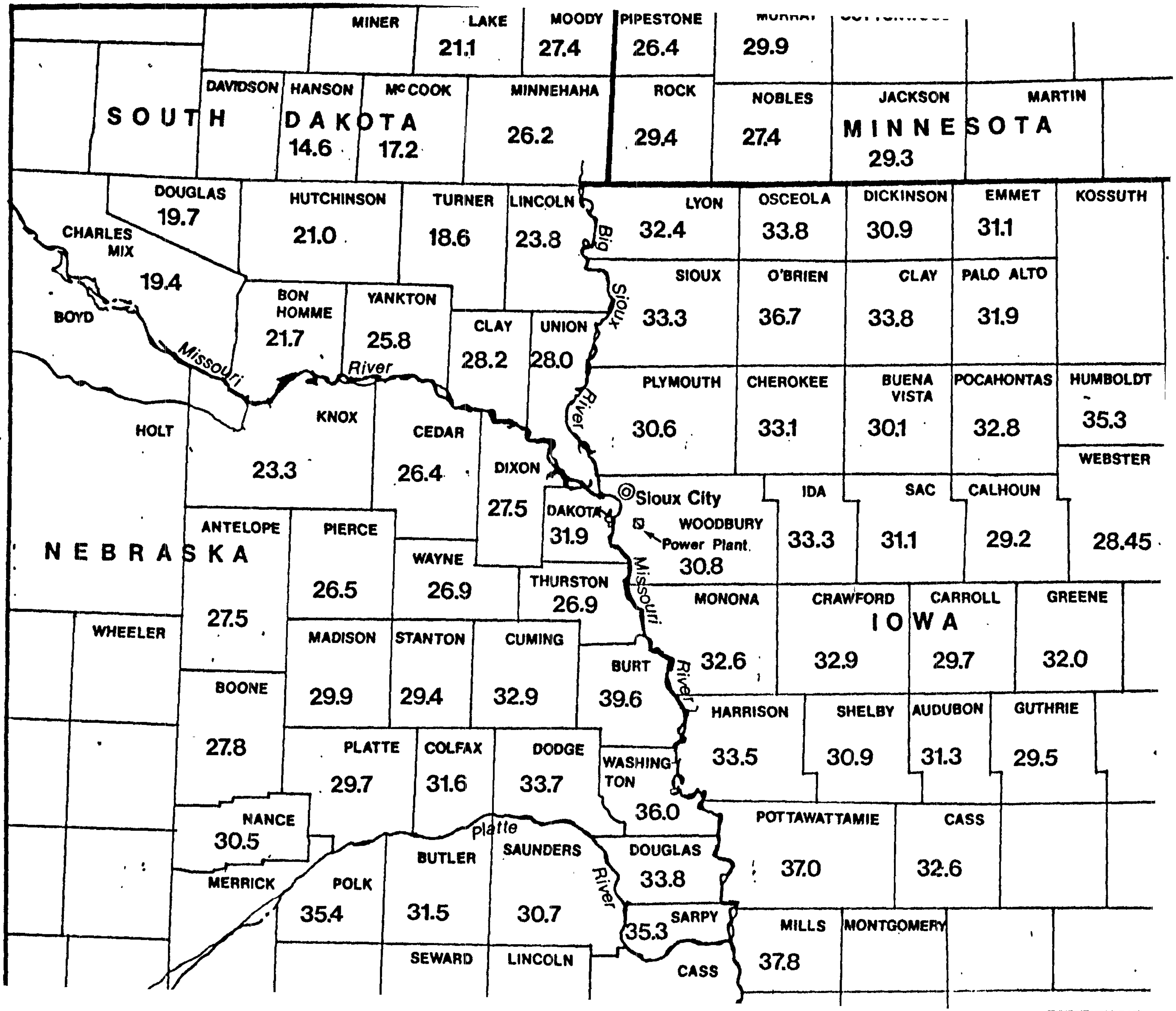

Figure III-5. Soybean yields (Bushels/acre) by county; 1969.

and III-7. Data for 1978 is shown only for Iowa since census results for Nebraska, South Dakota and Minnesota have not yet been published. This is shown in Figures III-8 and III-9.

Trends in normal yield variation can be observed from the map. Nebraska and South Dakota generally have lower yields than Iowa, with the exception of counties along the rivers. Also, 1974 yields were considerably less than those in 1969, probably due to low rainfall conditions. Excluding air pollution, soil conditions and rainfall variation are probably the two most important factors for yield variation.

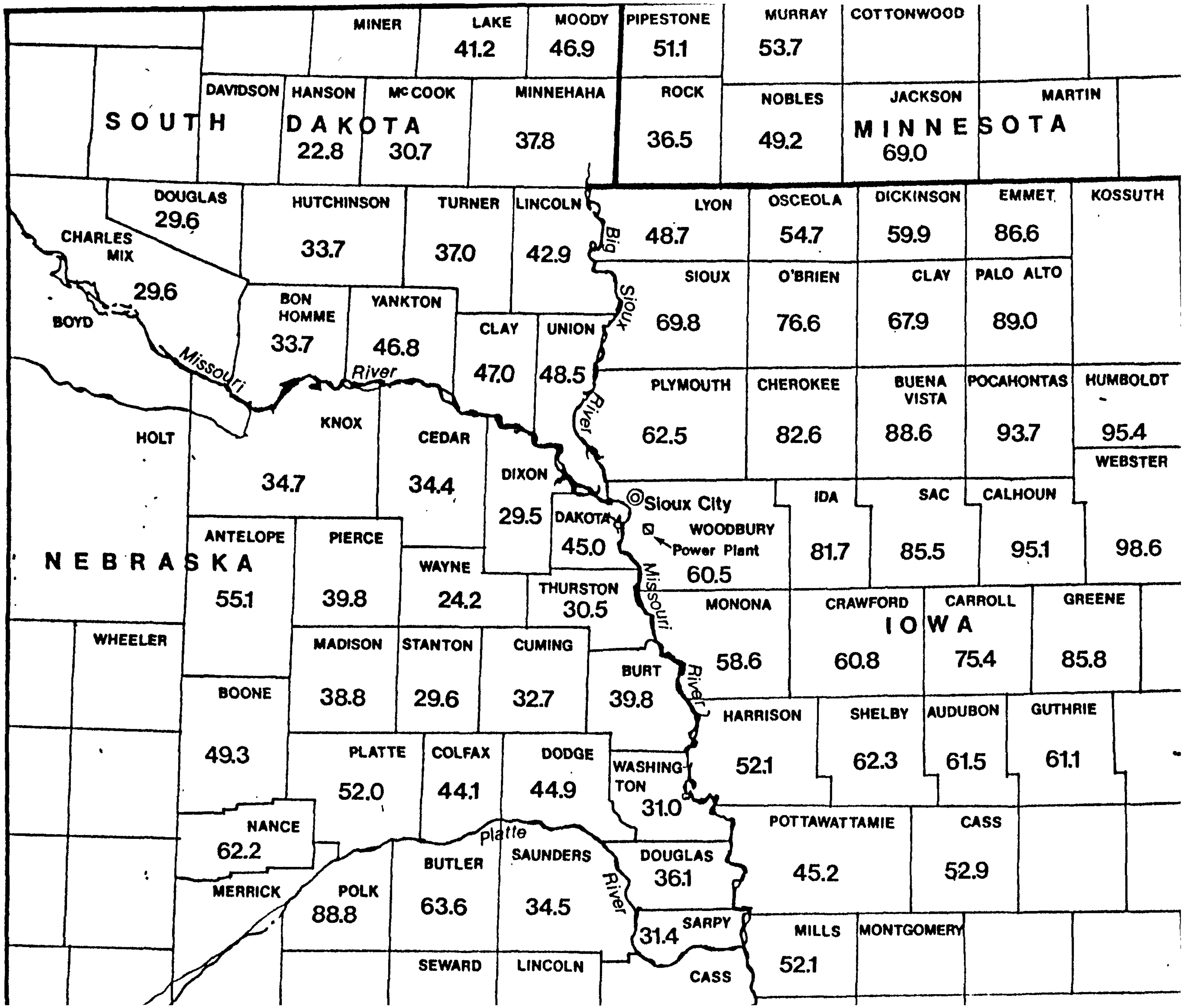

Figure III-6. Corn yields (Bushels/acre) by county; 1974.

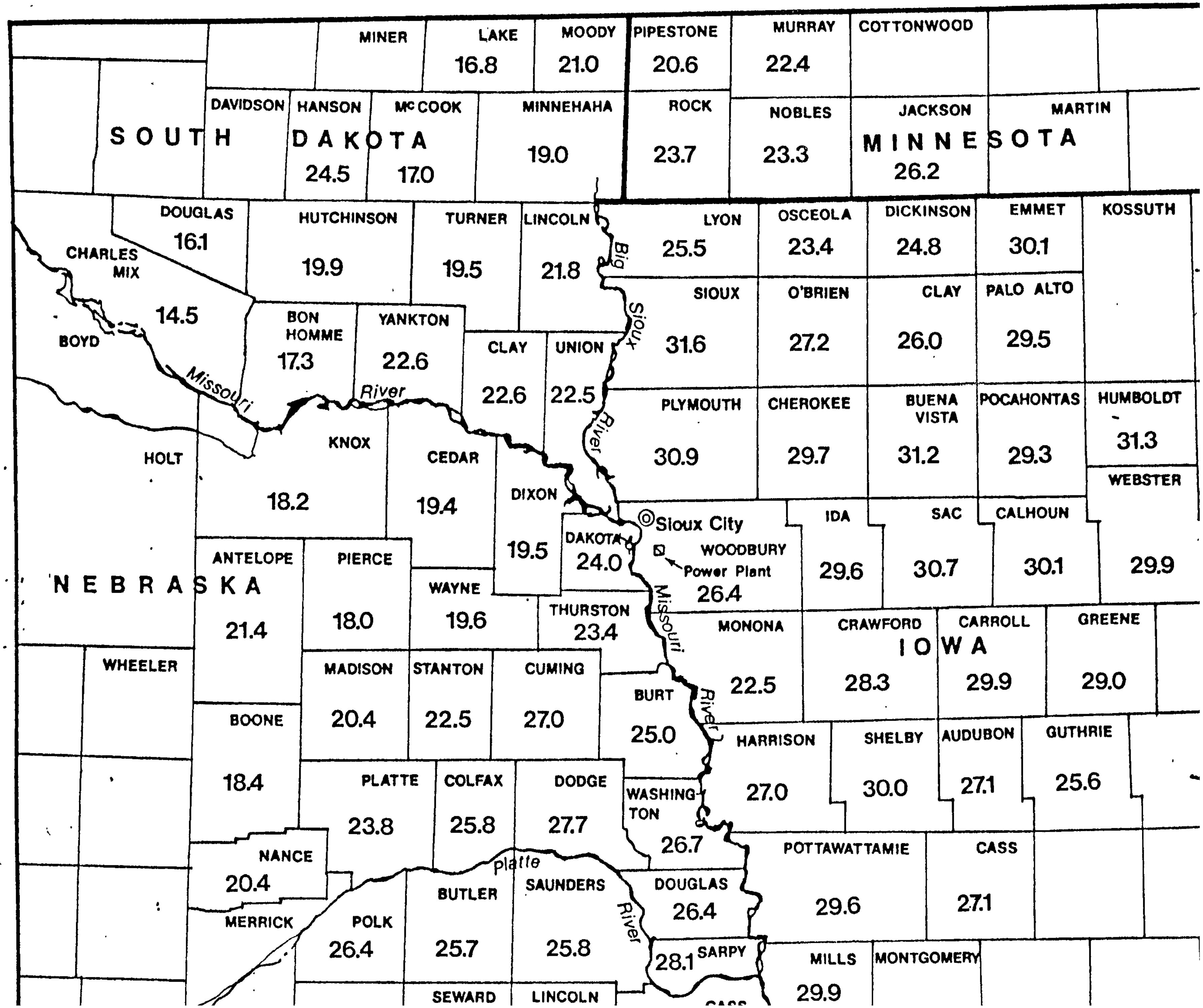

Figure III-7. Soybean yields (Bushels/acre) by county; 1974.

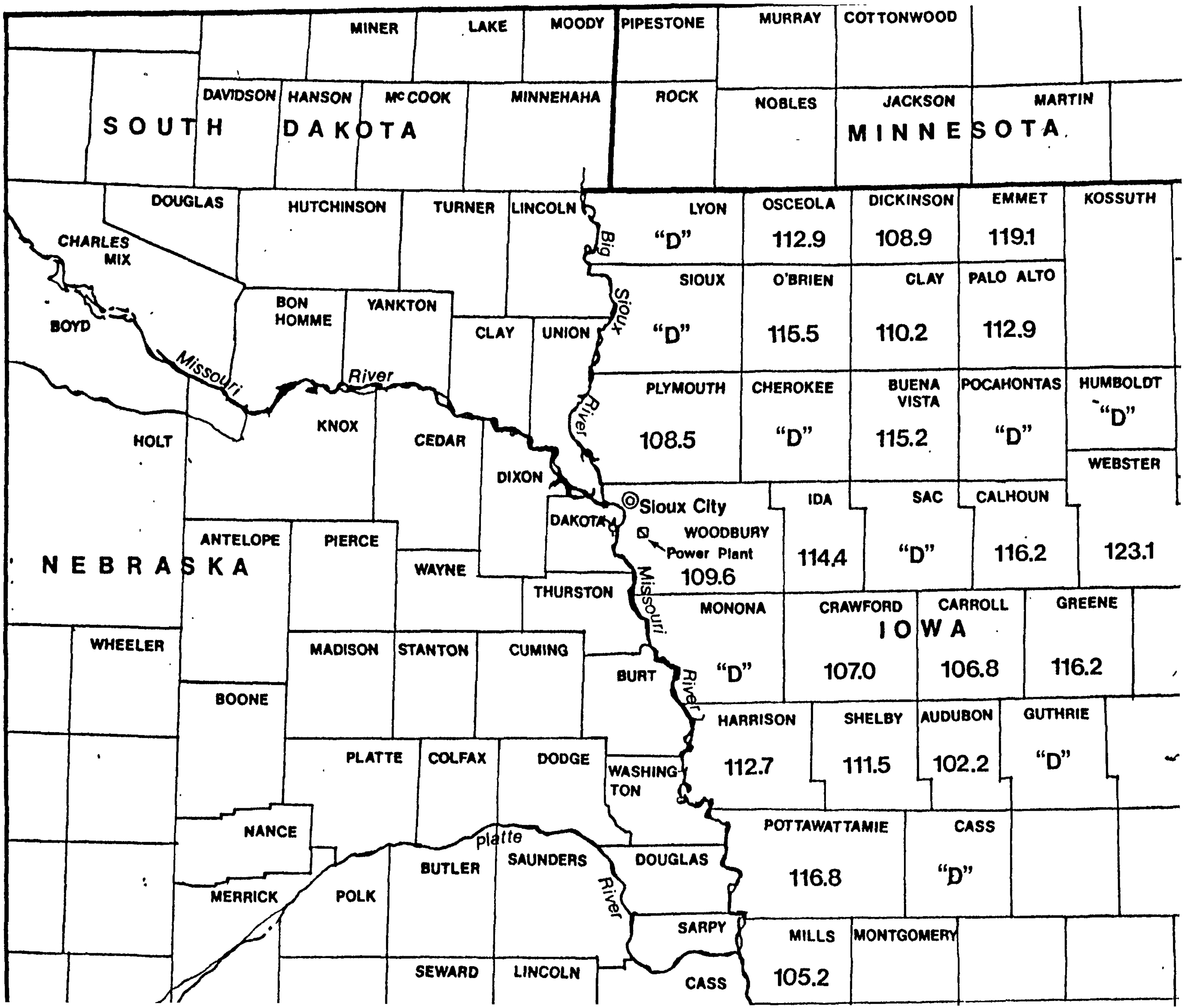

Figure III-8. Corn yields (Bushels/acre) by county; 1978.

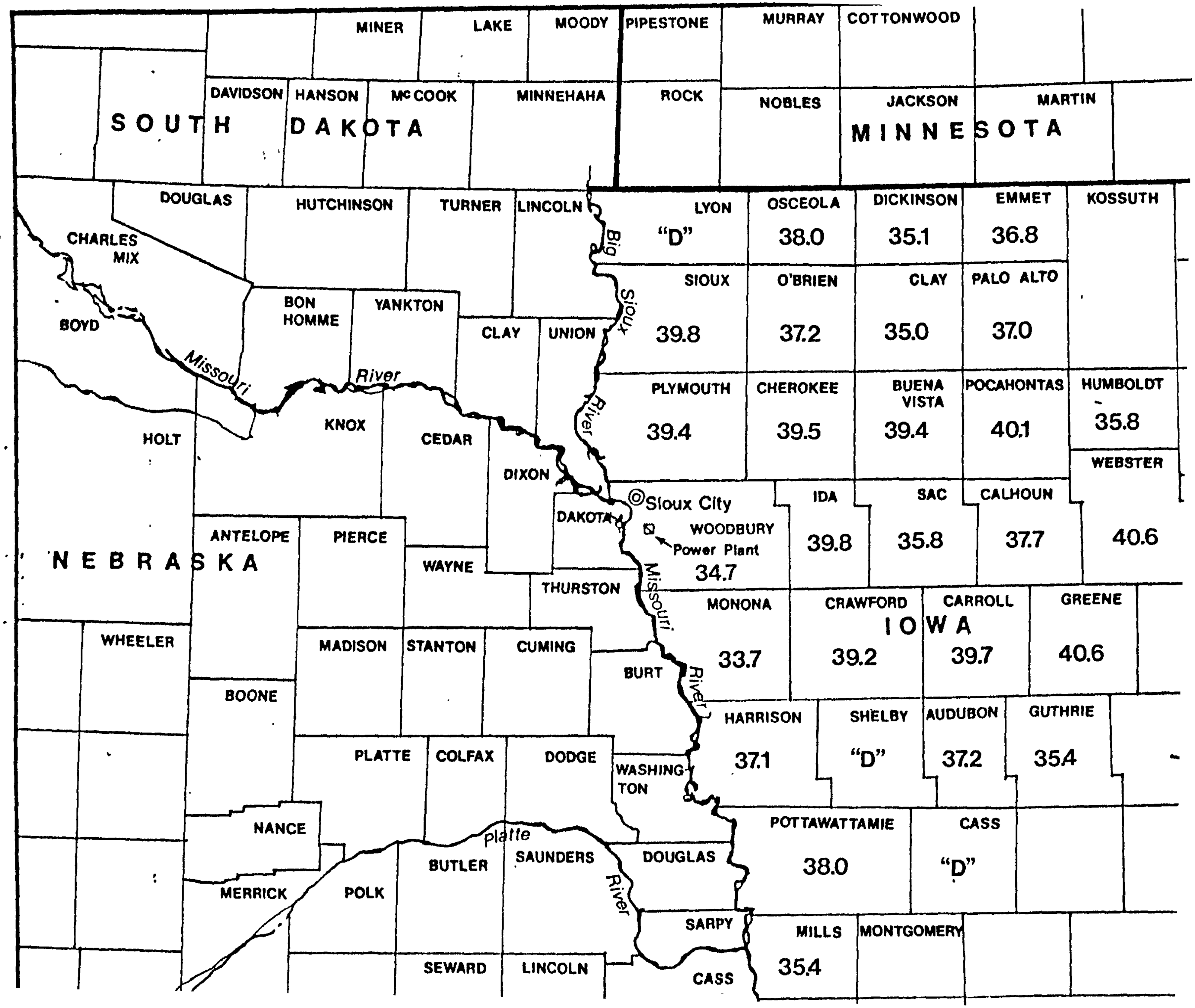

Figure III-9. Soybean yield (Bushels/acre) by county; 1978.